'An Experimental Research on some Standards of Light." By J. E. PETAVEL. Communicated by LORD RAYLEIGH, F.R.S. Received July 31,—Read November 16, 1899.

The standards of light may be divided into two main divisions, viz. :—

1. Flame standards.
2. Incandescent standards.

The first class comprises such standards as depend for their constancy on the rate at which chemical combination is going on. Almost all the standards in actual use come under this division. The British candle, the Methven standard,* the Harcourt† pentane standard, the Hefner-Alteneck‡ amyl acetate lamp, the Carcel lamp, and the acetylene§ burner are among the best known.

Apart from the large number of independent investigators who have carried out researches as to the relative merits of these sources of light, reference may be made to the reports of several committees which have been appointed in this and other countries to investigate the subject.‖

The general conclusions reached may be fairly summed up by saying that the pentane gas standard and the amyl acetate lamp are the lights which, from every point of view, have been found most satisfactory. Of the two, the Hefner-Alteneck lamp is the better known, and has been the subject of the more complete experimental study ; it may be taken as fairly representative of its class. The light emitted, as in the case of all the other flame standards, is seriously affected by atmospheric impurities. Liebenthal¶ has shown that, if x represent the

* 'Journal of Gas Lighting,' vol. 40, p. 42, 1882.

† See 'Brit. Assoc. Proc.,' 1877, p. 51, and 1898, p. 845; also 'Report of the Standard of Light Committees,' as below.

‡ 'Elektrotechnische Zeitschrift,' vol. 5, p. 20, 1884; also 'Electrical Review,' vol. 42, p. 759, 1898.

§ Proposed by Violle, Ch. Féry and Fessenden (see 'Comptes Rendus,' vol. 122, p. 79, 1896; also 'Comptes Rendus,' vol. 126, p. 1192, 1898).

‖ See Blondel's Report to the Congrès International des Electriciens at Geneva, 1896; Report of the Standard of Light Committee's meeting of the Institute of Gas Engineers, May, 1895, 'Journ. of Gas Lighting,' vol. 65, p. 1007, 1895; Report of the Standards of Light Committee to the British Association, 1888, p. 39; Dibden's Report to the Metropolitan Board of Works, 1885; Gas Institute Committee, 1884, and Board of Trade Committee; Preliminary Report of the Sub-committee of the American Institute of Electrical Engineers, 'Transactions,' vol. 13, p. 135, 1896; Rapport der Photometrie Com. der Vereeniging van Gasfabrikanten in Nederland, 'Journ. für Gasbeleuchtung und Wasserversorgung,' vol. 37, p. 613, 1894.

¶ 'Elektrotechnische Zeitschrift,' 1895, vol. 16, p. 655.

quantity of water vapour in litres per cubic metre of air, the light L sent out will vary according to the formula—

$$L = 1{\cdot}049 - 0{\cdot}0055x.$$

This will cause a variation of about 4 per cent. from one season of the year to another. The variations due to this cause are stated to be still more marked in the Harcourt and Carcel lamps.

Again, if x_1 represent the quantity of carbon dioxide present in the atmosphere, measured in litres per cubic metre, the light will be given by the formula—

$$L = 1{\cdot}012 - 0{\cdot}0072x_1.$$

Variations in the height of the flame are of the greatest importance. If h is the height—

$$L = 1 + 0{\cdot}025\,(h - 40),$$

or

$$L = 1 - 0{\cdot}030\,(40 - h),$$

according as h is above or below 40 mm.* The mean variation is, therefore, over $2\frac{1}{2}$ per cent. per mm. Owing to the bright halo which surrounds the flame, it is by no means easy to adjust the height correctly.

Finally, although it was at first stated that the degree of purity of the amyl acetate had no very considerable influence on the light, this has of late been denied, some authorities going so far as to state that sufficiently pure amyl acetate cannot be obtained in France.†

These facts will suffice to show that the variations are mainly due to causes inherent in this class of standard. Some of the difficulties can be obviated by providing a chemically pure atmosphere, and researches are being carried out in America in this direction, but it is obvious that any such improvement will involve a considerable complication of the apparatus.

Incandescent Standards.

In the case of standards of this class, the constancy of the light depends essentially on the constancy of the temperature at which the radiating body is kept, and on the constancy of the emissivity of the body at that temperature.

The temperature may be fixed by some definite physical phenomena as in the Blondel and Violle standards, or it may be determined in a more or less arbitrary manner, as in the Lummer and Kurlbaum standard.

* 'Journ. für Gasbeleuchtung und Wasserversorgung,' vol. 31, p. 583, 1888, or 'Elektrotechnische Zeitschrift,' vol. 9, p. 96, 1888.

† 'Rapport sur les Unités Photométriques,' A. Blondel, Congrès International des Electriciens, Genève, 1896.

Any solid substance that would not disintegrate at a temperature of about 1700° C. might, *à priori*, be chosen as a radiator. It has, however, been shown that most of the oxides when maintained at these high temperatures undergo a change in their emissive properties, and cannot, therefore, be used for the purpose we have in view.* The choice thus seems restricted in practice either to carbon or to one of the metals of the platinum group.

Before passing on to the experimental part of the work, it may be well to recapitulate the necessary qualifications of a standard of light. The requirements may be briefly summed up under three heads :—

1. The standard must remain constant.

The slow periodic variations of the amyl acetate lamp which extend over a period of several months are as much to be avoided as the flickerings of the candle or the hourly changes of the Carcel lamp.

2. The standard should be reproducible.

This condition is satisfied when the standards reconstituted by independent investigators show no measurable variation between one another.

3. The light emitted should be as nearly as possible of the same spectral composition as that of the chief artificial lights now in common use.†

On the Intrinsic Brilliancy of the Crater of the Arc.

For many years it had been noticed that the area of the crater of an electric arc when burning between carbon poles increased about in proportion to the current; also that the light emitted increased in the same ratio as the area of the crater.‡ These and other facts led to the conclusion that the temperature of the crater remained constant. The hypothesis was put forward that this temperature was the boiling point of carbon, this theory being supported by the experiments made in 1892 by J. Violle.§ In the same year it was proposed simultaneously by Swinburne, S. P. Thompson, and Blondel,‖ that the crater of the arc should be used as a standard of light, Blondel publishing a series of experiments illustrating the way in which the new standard might be used.

In 1894 A. Trotter¶ proved that when the arc is not silent the crater

* Nichols and Crehore, 'Trans. of the Amer. Inst. of Electrical Eng.,' vol. 13, p. 190, 1896.

† Strictly speaking, it is only when two lights are of the same spectral composition that the ratio of their intensities can be expressed by a single figure.

‡ Professor S. P. Thompson's Cantor Lectures, 1895; see also "The Electric Arc," by Mrs. Ayrton, 'The Electrician,' vol. 34, p. 399, 1895.

§ 'Journ. de Physique,' 3 sér., vol. 2, p. 545, 1893, and 'Comptes Rendus,' 1892, p. 1274.

‖ See 'Proc. of the Int. Electrical Congress at Chicago,' 1893, pp. 259, 267, 315.

¶ 'Roy. Soc. Proc.,' 1894, vol. 56, p. 262; see also "Effect of Pressure on the Temperature of the Arc," E. Wilson and C. F. Fitzgerald, 'Roy. Soc. Proc.,'

is formed by a point or line of very high intrinsic brilliancy rotating at a speed of from 50 to 450 revolutions per second.

The existence of the above mentioned phenomenon forms a serious objection to the use of the electric arc as a primary standard, but it does not, *per se*, render its use impossible.* Finally, the variation of the intrinsic brilliancy of the crater is a question which in itself offers considerable interest.

The points on which the present work bears are threefold—

1. What is the average intrinsic brilliancy of a normal (silent) arc ?
2. When the conditions are carefully specified, are the variations still too great to allow of the use of this source of light as a standard ?
3. What variations can be obtained by the use of excessive currents and current densities, and by surrounding the arc with an enclosure maintained at a very high temperature ?

To obtain consistent results the observations must be made on a very small area selected from the central portion of the crater.

The diaphragm used for this purpose is shown in fig. 3. The opening, d, is 1·47 sq. mm. in cross-section.† The diaphragm is shaped much like the tuyere of a blast furnace, and being kept cool by a water circulation it can be placed within a very short distance of the crater of the arc.

The next question involved was the determination of the best relative position of the carbons. In the usual arrangement of the arc the centre of the crater is hidden by the negative carbon. A modification of this arrangement, used by Blondel, which consists in slanting the carbons and placing the positive slightly behind the negative, was found not to be entirely satisfactory. An attempt was made to take the observations through a hole drilled out of the negative carbon (see fig. 1), but when the arc was started this hole became filled with mist, and the plan had to be given up.

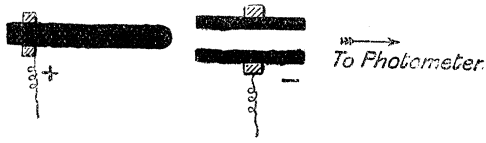
Fig. 2 shows diagrammatically the next arrangement which was tried. The carbons n_1, n_2, n_3, are negative, and form the edges of an equilateral pyramid, the axis of which is in the prolongation of the positive carbon P. The summit of the pyramid is at the point P. The crater formed on the positive carbon by these three arcs is in

vol. 58, p. 174, 1895; vol. 60, p. 377, 1897; see also the account of the discussion on this subject on the 19th February, 1897, at the Société Française de Physique.

* On this subject see Captain Abney, 'Journ. of the Inst. Elec. Eng.,' vol. 28, p. 443, 1899.

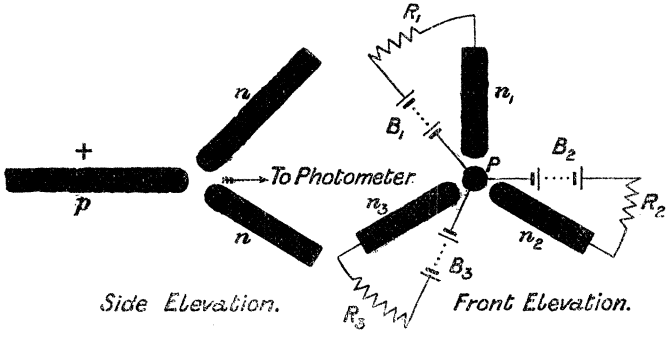
† It has been shown by Professor S. P. Thompson (see 'Phil. Mag.,' vol. 37, p. 120, 1893) that when diaphragms of very small diameter are used the thickness of the plate in which the aperture is pierced introduces a serious error in the measurements. This difficulty was avoided by counter-sinking the opening.

FIG. 1.



full view, and good results might have been obtained in this manner. Unfortunately this disposition had to be abandoned, as it soon became evident that it was impossible for one observer to adjust the currents in the three independent electrical circuits, to feed up the four carbons, and to make all the electrical and photometric readings.

FIG. 2.—P, positive pole ; n_1, n_2, n_3, negative poles ; R_1, R_2, R_3, variable resistances ; B_1, B_2, B_3, batteries.



The disposition which was finally adopted is shown in fig. 3. The diaphragm d screws into a screen s. This screen is supported on a system of pivots and levelling screws, so that it can be raised, lowered, or turned round a vertical or horizontal axis. The opening d can thus be directed to any portion of the crater. The positive carbon is horizontal, and so placed that its axis coincides with the axis of the photometer.

Two distinct series of experiments were carried out: one with the arc placed in a metallic enclosure kept at about 20° C. by a water circulation, the other in the enclosure shown in fig. 3. The temperature of this enclosure varied from the melting point of silver to near the melting point of platinum, according to the amount of power expended in the arc. Referring to fig. 3, c is a carbon crucible surrounded by a thick layer, b, of firebricks and refractory clay. The outer covering a is of asbestos. Both the high and low temperature enclosures were provided with a small camera obscura (not shown in the

FIG. 3.—*a*, asbestos box; *b*, lining of refractory bricks; *c*, graphite crucible; *d*, diaphragm; *s*, screen.

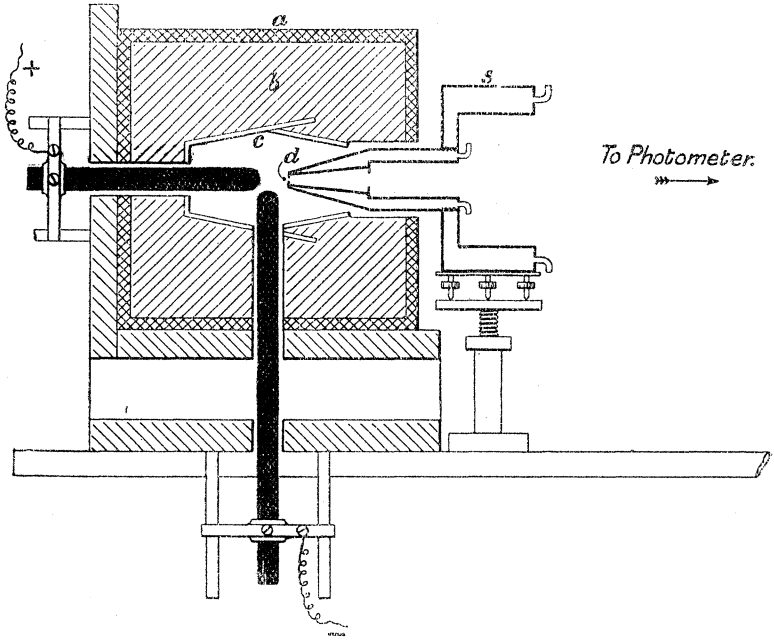


figure), by aid of which the relative positions of the carbons could be adjusted and the length of the arc measured.

"Apostle" carbons were used in all the experiments. The size of the positive carbon varied from 6 to 25 mm. in diameter.

To obtain reliable results a sufficient current density must be used to give a fairly large crater. The arc must also be sufficiently stable for the crater to remain some considerable time without shifting its position. Finally, it is desirable that the arc should be burning in a normal manner, and therefore neither hissing nor roaring.

Given these conditions, it is impossible to vary either the current, the electromotive force, or the length of arc, within very wide limits.

In the experiments recorded in Table I, the mean intrinsic brilliancy is 147 candle power per square millimetre; the variations from the mean amounted to 10 per cent.

Table II gives experiments made under similar conditions, but with the enclosure in which the arc was burning at a temperature of over 900° C. The average intrinsic brilliancy calculated from this table is 143, or about 3 per cent. lower than when the enclosure was at the ordinary temperature. It would, however, be unwise to attach too much importance to this change. The difficulty of obtaining consistent

Table I.—"Silent" Arcs. Enclosure at about 20° C.

Electromotive force in volts.	Current in amperes.	Power in watts.	Diameter of the positive carbon in mm.	Current density in amperes per sq. mm. of cross-sectional area of positive carbon.	Length of arc in mm.	Intrinsic brilliancy of the crater in candle-power per sq. mm.[1]
65·0	8·1	526	8	0·161	4·8	136
64·5	7·0	452	8	0·139	..	141
72·0	10·3	742	8	0·205	6·0	143
70·3	7·3	513	6	0·258	..	147
61·7	6·0	370	6	0·212	5·1	154
62·0	9·1	564	6	0·322	6·0	160

[1] Each of the figures in this column is the mean of a number of photometric observations.

Table II.—"Silent" Arcs. Enclosure above 900° C.

Electromotive force in volts.	Current in amperes.	Power in watts.	Diameter of the positive carbon in mm.	Current density in amperes per sq. mm. of cross-sectional area of positive carbon.	Length of arc in mm.	Intrinsic brilliancy of the crater in candle-power per sq. mm.[1]
83·0	11·0	913	8	0·219	..	136
57·0	10·9	621	15	0·061	..	142
61·0	8·6	525	8	0·171	6·0	152

[1] Each of the figures in this column is the mean of a number of photometric observations.

results is considerable, and a 3 per cent. variation is well within the experimental error.

The conclusions we have reached may be summed up as follows:—

1. The intrinsic brilliancy of the crater of a silent arc is about 147 candle power per square millimetre.

2. Even when the most favourable conditions are selected, and the intensity of current and the length of the arc are maintained constant, it is difficult to obtain consistent results, variations of over 5 per cent. being by no means unfrequent. The crater of the arc does not, therefore, possess the qualities required of a standard.

3. Variations in the size of the carbons, in the intensity and density of the current, in the length of the arc, and in the total power expended (as long as the arc is kept silent), will not cause the intrinsic brilliancy to vary more than 10 per cent. on either side of the mean.

4. No sensible variation in the intrinsic brilliancy, and therefore in the temperature of the crater, is produced by placing the carbons in an enclosure maintained at over 900° C.

With regard to the constancy of the temperature of the crater, these results are not without importance.

Having this question in view, it was necessary to determine what were the effects of extreme variations of current density and power.

In Tables III and IV will be found the results of observations taken when the arc was hissing.*

Table III.—"Hissing" Arcs. Enclosure at 20° C.

Electromotive force in volts.	Current in amperes.	Power in watts.	Diameter of the positive carbon in mm.	Current density in amperes per sq. mm. of cross-sectional area of the positive carbon.	Length of arc in mm.	Intrinsic brilliancy of the crater in candle-power per sq. mm.[1]
70·0	15·8	1106	8	0·314	4·8	136
42·0	21·6	907	8	0·410	1·2	143
53·0	25·8	1367	8	0·514	2·9	157
44·0	50·0	2200	15	0·283	..	160

[1] Each of the figures in this column is the mean of a number of photometric observations.

It will be seen that the current varied from 6 to 50 amperes, the current density from 0·03 to 0·51 ampere per square millimetre, and the power from 370 to 2800 watts.

The lowest photometric readings gave 119, and the highest 160 candle power per square millimetre.

* The word "hissing" is used here as being the generally accepted term. It is only when the current density is small that it is actually descriptive of the sound made; as the current increases, the pitch rises, until with a very short arc and a current density of about 1 ampere per square millimetre, the sound is between a whistle and a scream. The arc then assumes a very peculiar aspect, a pointed blue flame, like the flame of a blow-pipe, being sent out from the crater. This effect was most marked when the high temperature enclosure was used. With the above current density the entire carbon becomes white hot and burns away with great rapidity; an increase in the intrinsic brilliancy seems also to take place. Unfortunately, it was not found possible under these circumstances to obtain reliable photometric observations.

Table IV.—"Hissing" Arcs. Enclosure above 900° C.

Electro-motive force in volts.	Current in amperes.	Power in watts.	Diameter of the positive carbon in mm.	Current density in amperes per sq. mm. of cross-sectional area of the positive carbon.	Intrinsic brilliancy of the crater in candle-power per sq. mm.[1]
79·0	18·0	1422	15	0·102	119
45·6	42·0	1915	15	0·238	121
60·3	18·6	1122	25	0·038	130
52·0	55·0	2860	25	0·112	133
41·0	43·4	1779	25	0·088	137
50·0	39·3	1965	15	0·222	142

[1] Each of the figures in this column is the mean of a number of photometric observations.

If we assume that the formula :*

$$t - 400 = 889{\cdot}6\sqrt[6{\cdot}9]{b}$$

(t = temperature in degrees centigrade, b = intrinsic brilliancy in candle power per square centimetre), holds good for carbon at these high temperatures, the above change in candle power corresponds to a variation of temperature of from 3866° to 4018° C. The total alteration in absolute temperature thus works out at 4 per cent. Observations made on silent arcs (Tables I and II), reduced in the same manner, give the extreme limits of temperature as 3935° and 4018° C., or a change of 2 per cent. in the absolute temperature.

These variations are somewhat greater than we should meet with in the case of substances boiling at ordinary temperatures. It must, however, be borne in mind, that even in the case of a silent arc, the crater is the seat of several secondary phenomena, which under certain circumstances may affect the boiling point.† The term boiling point is in itself misleading, as it seems possible, if not probable, that at atmospheric pressure carbon does not become liquid, but like carbon dioxide, passes direct from the solid to the gaseous state. It has frequently been stated that impurities cannot affect the temperature of the crater, as all known bodies become gaseous at a lower temperature. The experimental data to substantiate this are entirely wanting; silica, lime, alumina, magnesia, and other substances are solid at the tem-

* 'Phil. Trans.,' vol. 191, A, p. 515, 1898.

† Mrs. Ayrton, "On the Hissing of the Electric Arc," 'Journ. of the Inst. of Elec. Eng.,' vol. 28, p. 401, 1899; also Dr. J. A. Fleming's remarks during the discussion of Mrs. Ayrton's paper, p. 439.

perature of melting platinum, and it is difficult to predict at what temperature they volatilise.

Taking everything into consideration, it may therefore be said that the present experiments confirm the theory that the crater of the arc is at the temperature of volatilisation of carbon.

The earliest determinations of the intrinsic brilliancy of the crater were made in 1878 at Chatham under the direction of the Royal Engineers' Committee.* The results varied from 39 to 442 candle power per square millimetre, the mean value being 110. With regard to more recent researches, Trotter gives the intrinsic brilliancy as 64, Weber as 70, and Blondel as 158 candle power per square millimetre. With the exception of those of Blondel all previous results are very much lower than the values I have obtained. The discrepancy may be attributed to the fact that instead of using a diaphragm to select the rays from the centre of the crater, the first named observers estimated the total area of the crater, and compared it with the total amount of light.

On the Lummer and Kurlbaum Incandescent Platinum Standard.

In 1894 Drs. O. Lummer and F. Kurlbaum proposed a new standard of light.† A strip of platinum foil 25 mm. wide, 0·015 mm. thick is brought to incandescence by an electric current of about 80 amperes. The temperature is increased until one-tenth of the total radiation is transmitted through a water trough 2 cm. in width. This ratio is determined by means of a bolometer. The construction of the instruments require the greatest care, and three months had passed before I was able to obtain the first observations. The instruments used for this work are shown in fig. 4. The explanation appended to this drawing is sufficient to render further description unnecessary.

It would be useless to give details of the experiments which in the main confirm the results already obtained by Lummer and Kurlbaum.

With the same apparatus used in the same manner the light is practically constant as long as the ratio of radiations is adjusted to 1/10 per cent.

The adjustment of the temperature of the platinum foil with the required degree of precision is, however, most tedious, and in fact all but impossible, except under the most favourable conditions. This consideration, together with the complicated nature of the apparatus, render this light impracticable as a working standard.

At the beginning of the present paper it has been pointed out that a

* R. E. Committee extracts for 1879; Report of the Electric Light Experiments carried out at the School of Military Engineering at Chatham.

† 'Berichte der Preuss. Akademie,' 1894, p. 227; 'Elektrotechnische Zeitschrift,' 1894, p. 475.

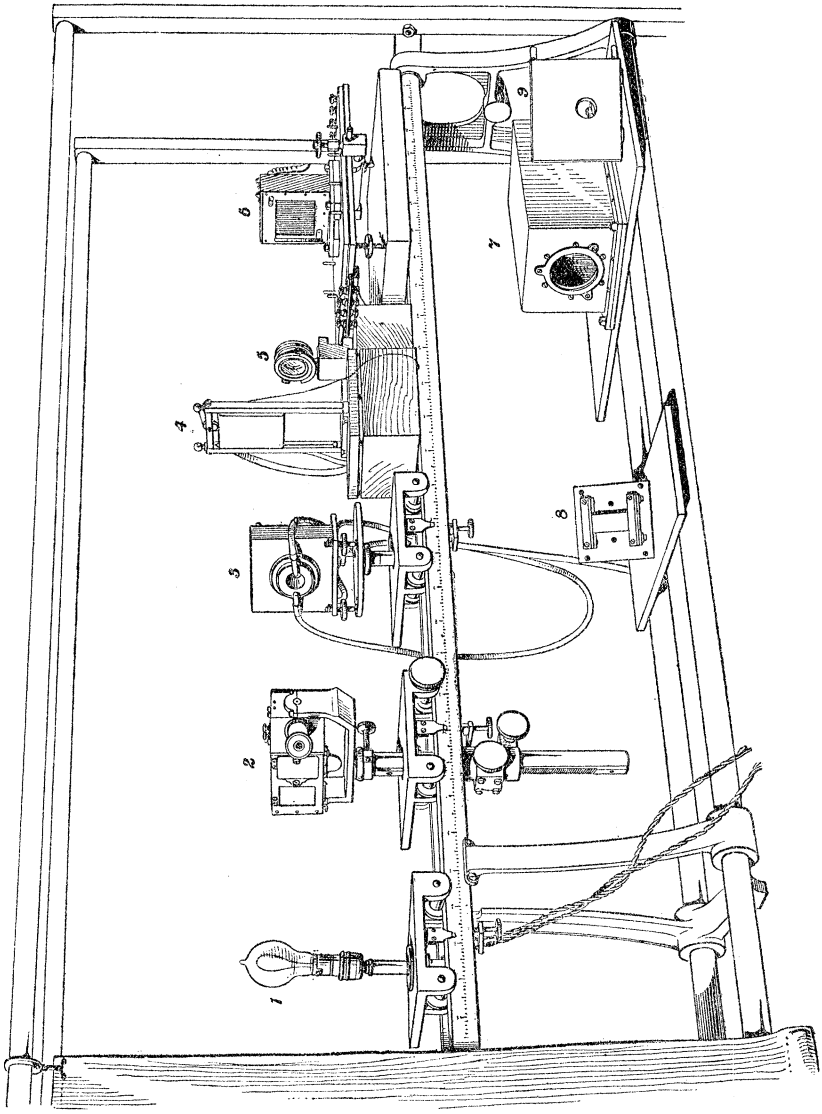


FIG. 4.—Apparatus used for the investigation on the Lummer and Kurlbaum incandescent platinum standard :—

1. Incandescent lamp serving as standard of reference.
2. Lummer and Brodhun photometer head.
3. Enclosure in which the incandescent platinum foil is placed with the 1 sq. cm. diaphragm.
4. Screen to cut off the radiation from the bolometer.
5. Water-trough, with quartz sides 2 cm. apart.
6. Bolometer with the cover removed to show the films.
7. Bolometer cover.
8. Clips for holding the incandescent platinum foil; this plate fits on to the back of the enclosure 3.
9. One of the water circulation diaphragms used to keep any extraneous radiation from the bolometer.

standard must be constant, reproducible, and must emit light of a suitable colour. We have just seen that the source of light under consideration may be regarded as fulfilling the first of these conditions; with regard to the second and third, the conclusions are less favourable.

By definition, the ratio between the total radiation and that transmitted through the water trough must be as ten to one, 1 per cent. error in the electrical measurements causing 3 per cent. change in the light. To obtain the required degree of precision the galvanometer deflections must be reduced to equality. Three methods are available:—

1. The bolometer current may be reduced in the ratio of one to ten.
2. A 1/10th shunt can be introduced into the galvanometer circuit.
3. The distance between the bolometer and the radiator may be varied in the ratio of 1 to $\sqrt{10}$.

None of these methods is entirely satisfactory. The reduction of the current through the bolometer involves a considerable complication of the apparatus, and interferes with the steady working of the instrument. It is also by no means impossible that the resulting change in the temperature of the bolometer films may change their coefficient of absorption. With a shunted galvanometer, temperature changes and thermo-currents are a frequent source of error. The most reliable method is to change the distance of the radiator; but here again two objections arise. The enclosure containing the platinum foil is rarely at a temperature so closely approaching that of the bolometer films that shifting this large surface leaves the instrument unaffected. The law of inverse squares cannot strictly be applied, as the rays of light are refracted when passing through the water trough. In practice, marked variations were obtained when the method of determining the ratio of the two radiations was altered.

The use of another form of bolometer produced a considerable change in the light emitted. The bolometer films are coated with platinum black by electrolysis. The composition of the bath, the electromotive force, and the current have been specified; but it was found that the temperature of the bath and the resistance of the film affected the nature of the deposit obtained.

Finally, the spectral composition of the light is unsatisfactory, the colour being much too red.

We are thus driven to the conclusion that this light does not possess all the qualities required of a primary standard. Under certain circumstances it may be of the greatest value as a standard of reference. It is used in the Reichsanstalt to check the values of the Hefner lamps; for purposes of this kind it is well suited, and might with advantage be more frequently used.

Preliminary Research on the Molten Platinum Standard of Light.

The use of molten platinum as a standard of light was first proposed by J. Violle* at the Congrès International des Electriciens on the 21st of September, 1881.† In 1884 Violle published an account of his experiments with the new standard, which was adopted in the same year by the Conférence Internationale pour la Détermination des Unités Electriques on the 2nd of May, 1884.‡ The adoption was confirmed by the Congrès International des Electriciens on the 21st of May, 1889, when it was specified that the practical unit should be the *bougie décimale*, and by the International Congress in Chicago in 1893, and the Congrès International des Electriciens at Geneva in 1896, when the use of the Hefner lamp as a practical standard was recommended.

Since the adoption of this unit the aim of most of the experimental work on the subject has been not so much to find a suitable method of using the Violle standard as to obtain a substitute for it. These efforts have resulted in the well-known instrument devised by W. Siemens§ for fusing platinum foil, and in the proposal made by C. R. Cross‖ to use as a practical standard the light emitted by a thin platinum wire at its melting point.

Physiological considerations render such a thing as an instantaneous photometric reading an impossibility, and herein lies the principal reason why the above proposals have had to be abandoned. Apart from this fact, it is extremely doubtful if either in the case of fine wire or thin foil the break occurs actually at the temperature of fusion of the metal.¶ Cross admits that there were considerable differences in the quantity of light emitted per unit area when the diameter of the wire was changed. In connection with the present work a number of experiments were tried, both with wire and foil, but the results were by no means encouraging.

* For Violle's researches see 'Comptes Rendus,' vol. 88, p. 171, 1879; vol. 85, p. 543, 1879; vol. 92, p. 866, 1881; 'Lumière Electrique,' vol. 14, p. 475, 1884; 'Annales de Chimie et de Physique,' sér. 6, vol. 3, p. 373, 1884.

† 'Comptes Rendus du Congrès International des Electriciens,' Paris, 1881. Assemblée générale, Troisième Séance, p. 50. See also 'Procès-Verbaux de la Conférence Internationale pour la Détermination des Unités Electriques.' Troisième Commission, Séance du 20 Octobre, 1882, p. 131.

‡ 'Conférence Internationale pour la Détermination des Unités Electriques.' Deuxième Session, Troisième Séance, Mai 2, 1884, pp. 23, 115. "L'unité de chaque lumière simple est la quantité de lumière de même espèce émise en direction normale par un centimètre carré de surface de platine fondu, à la température de solidification. L'unité pratique de lumière blanche est la quantité totale de lumière émise normalement par la même source."

§ 'Elektrotechnische Zeitschrift,' vol. 5, p. 244, 1884.

‖ 'Electrician,' vol. 17, p. 514, 1886.

¶ See 'British Association Fourth Report of the Standards of Light Committee,' App. II, 1888, p. 47.

As far as I am aware only one research has been carried out with a view of repeating the Violle standard on anything like the scale originally used. This research was made at the Reichsanstalt* in Berlin. The work proved unsuccessful, and a detailed account of the experiments has never been published. This renders it very difficult to suggest a reason why reliable results were not obtained.

In the case of molten platinum, owing to the high rate at which heat is being dissipated, it is quite possible for one part of the mass to be liquid while another part only a few millimetres distant is considerably below the temperature of solidification. This source of error should be minimised by the choice of suitable experimental conditions, and by reducing the results by some method similar to the one given below. Again, all the magnesia or lime bricks I have been able to secure contain a certain proportion of silica. This, as will be pointed out later, is sufficient to render them useless for the purpose in view. In the account of the Reichsanstalt experiments this difficulty is not mentioned.

In common with all other pure substances, platinum has a constant freezing point; the length of time, however, during which the constancy of temperature will be maintained, depends mainly on three factors.

If we take D to represent the quantity of heat dissipated by the platinum per unit time when at its temperature of solidification, H the heat supplied to the metal per unit time, and L the total latent heat of the mass, and supposing for the present that the thermal conductivity is very great, the time during which the temperature will remain constant will be—

$$t = \frac{L}{D - H}.$$

For the object we have in view the time of constancy must be made as great as possible.

One method of increasing the time t is to make H very nearly equal to D, or, in other words, to supply heat to the molten metal at nearly the same rate as the metal is losing it. We may supply the necessary quantity of heat H by means of an electric current; or, using a large surface of metal, we may keep the blow-pipe going on one part of the surface while the observations are being made on some other portion.

If we abandon the idea of supplying heat during the time the observations are being taken, the formula becomes—

$$t = \frac{L}{D}.$$

* 'Thätigkeitsberichte der Reichsanstalt,' 1890 and 1892—1894, or 'Zeitschrift für Instrumentenkunde,' vol. 11, p. 149, 1891, and vol. 14, p. 266, 1894.

In order to reduce the amount of heat dissipated we must place the platinum in an enclosure at nearly the same temperature as the metal itself, take the observations through a relatively small opening, and make the thermal insulation of the mass as perfect as possible. In the above formulæ, L being a function of the volume and D a function of the surface, we may, for any given circumstances, increase the time t by increasing the total volume of the metal.

But it now becomes necessary to take into account the thermal conductivity of the metal. Strictly speaking, any given portion of the surface can only be at the standard temperature t_s for the very small fraction of a second during which the solid film is forming; later on the surface is at some lower temperature $(t_s - n)$ where n is the temperature interval which is required to cause the heat to flow from the parts of the mass where the process of solidification is actually in progress to the surface at the same rate as it is there being dissipated. Thus by increasing the mass of the metal we cannot indefinitely increase the time available for the photometric observations. Unless the rate at which the heat is being dissipated at the surface under observation is made small, the temperature will not remain constant during the process of solidification, but will fall more and more rapidly as a larger proportion of the mass becomes solid.

On the Fusion of Platinum by an Electric Current.

From the considerations that have just been enumerated, the advantages of an electric method of heating the metal are at once apparent.

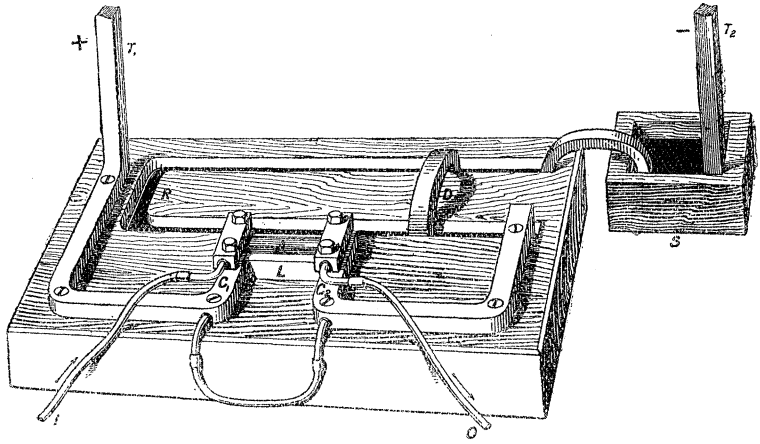
In the preliminary experiments a number of different forms of electric furnace were tried. In some cases the electric arc was used, in others the crucible was surrounded with a layer of graphite through which the heating current was passed. It is well known that at high temperatures platinum combines with carbon forming a carbide, and thus the use of graphite crucibles was out of the question.

It is unnecessary to give further details as the experiments were not successful. No material could be found that would resist the high temperature of the arc and the chemical action of the incandescent carbon, and at the same time not affect the purity of the platinum.

It was then decided to fuse the platinum by passing the current directly through the metal itself. The apparatus shown in fig. 5 was designed for this purpose. Some forty large secondary cells were, by aid of the mercury switch, connected in parallel on to two "'bus-bars." The current was carried by massive copper leads to the terminal T_1, and from there by a one square inch bar to the clip C_1 passing through the platinum bar A to the clip C_2. R is a U-shaped mercury trough serving as a variable resistance. The copper short-circuiting piece D

could be slid along the U so as to increase or diminish the effective length of the mercury. The clips C_1 and C_2 were hollow and kept cool by a water circulation. A rapid flow of water was also maintained over the surface of the mercury. The electric circuit was completed through the mercury switch S and an amperemeter.

FIG. 5.—Apparatus for the fusion of platinum bars by an electric current. A, platinum bar; C_1, C_2, copper clips in which the platinum is held; L, lime trough which supports the fused metal; R, mercury trough serving as a variable resistance; D, copper short-circuiting piece; S, mercury switch; T_1, T_2, massive copper leads to the battery terminals; I and O, water inlet and outlet.



With this arrangement currents up to 2000 amperes could be maintained for several hours. The platinum was supported by a trough, L, of some refractory material which was carefully cut to fit the metal bar. From the first it was evident that the principal difficulty would be to find a suitable material for this support. The weight of the molten metal acting on the supporting material gradually causes the shape of the trough to alter, and in a comparatively short time the cross-section of the metal becomes very irregular. The platinum then superheats in the place where the cross-sectional area has been most reduced, a spark occurs, and the molten metal thrown aside by the explosive force of the discharge, freezes before it has time to flow back into position. It is of course easy to re-weld the platinum, but the same difficulty will recur time after time and at more frequent intervals as the shape of the trough becomes more and more distorted. Some twenty bars of different shapes and sizes were used with the same result. Had it been possible to use larger bars, any small distortion of the trough would probably not have affected the

experiments. However, as already stated, 2000 amperes was the maximum current available, and with this current it was found impossible to melt bars of much more than 70 sq. mm. in cross-section.

The length of the span between the edges of the clips was usually 70 mm., but in some cases this length was reduced to 40 mm.

Lime, alumina and magnesia were the materials used for the troughs.

It became evident that small platinum bars could not be maintained for any length of time in the molten state when supported on the ordinary refractory materials, and it was decided to make use of metal supports.

The question of cost excluded the use of the metals of the platinum group, and in default of a better material the trough was made of nickel. A number of nickel plates insulated from each other by mica were bolted together so as to form a solid block. In this block a cylindrical groove was cut, its axis being perpendicular to the direction of the laminations. The nickel plates were 1·8 mm. in thickness, every alternate plate projecting 5 mm. on the sides and 6 mm. below. Through the channels thus formed a rapid circulation of water was maintained. The platinum bar was semi-circular in cross-section and deeply grooved on the lower side where it came in contact with the nickel. The shape was much the same as would be obtained by cutting an ordinary bolt in two along its axis, the edges of the V-shaped thread bearing on the nickel. In this manner the somewhat anomalous experiment of fusing platinum in a nickel crucible was successfully carried out. Needless to say that the anomaly is only apparent, the molten platinum did not come in contact with the nickel, but was supported in a shell of solid platinum. The cooling was so efficacious that the nickel crucible never once became red hot. When the metal is fused in this manner the quantity of heat lost is very considerable, and the effective cross-section of the bars had to be greatly reduced. The cross-sectional area, as measured from the bottom of the grooves, did not exceed 30 sq. mm. At the surface of the bar the central channel of molten metal was not more than 2 mm. in width. If the current were forced so as to melt a larger surface, the bottom of the threads softened sufficiently to allow the fused platinum to run through, thus causing the bar to break.

Even when this occurred the platinum was found to freeze rapidly enough to prevent it alloying with the nickel support.

If the above experiments were made on a larger scale some valuable results would certainly be obtained. By the use of a large welding transformer there should be no difficulty in fusing bars of ten or twenty times the cross-section of those used in the present instance. As will be seen below, good results can be obtained when the ordinary

oxy-hydrogen flame is used to fuse the platinum, but, taking everything into account, the electrical method, if carried out on a sufficient scale, would not only be more simple, but would afford a more ready means of varying the rate of cooling.

On the Fusion of Platinum by the Oxy-hydrogen Blow-pipe.

The object of the following researches was to repeat the work done some years ago by Violle, and to determine what are the best experimental conditions. It is a somewhat curious fact that, although Violle makes no mention of having encountered any special difficulties, his experiments have never been repeated with success. Even under the best conditions (such as are obtainable, for instance, at the Reichsanstalt) the results have not proved satisfactory. Under these circumstances, it seemed hardly advisable to attempt any further research in this direction. But the theoretical advantages of the Violle standard appeal strongly to anyone who has studied the standards of light now in practical use, and it was thought that, whatever the final result, the time spent in this study would not be lost.

The preliminary experiments occupied some considerable time, and nearly six months passed before the conditions under which the fusion should take place were clearly established. The platinum was fused several hundred times, the conditions being varied in every conceivable way. The shape of the furnace, the material of which it was made, the form of the blow-pipe, the relative proportion of the gases, in fact, everything that could have any bearing on the final result was in turn studied, and the most favourable conditions determined. The slightest impurity on the surface of the platinum has a considerable effect on the quantity of light emitted. When cold the surface always appears fairly bright and clean, but there is a temperature between a white and red heat at which the smallest impurity is clearly visible. At this temperature the platinum ingot, if it be quite pure, is very similar to a pool of molten glass. Any small impurity will cause a slight haze, resembling that produced on a mirror by a breath of moist air; if the impurities are present in a larger proportion the surface becomes very similar to a sheet of ground glass.

The necessary conditions to ensure a pure surface may be briefly summed up as follows:—

1. The platinum must be chemically pure.
2. The crucible must be made of pure lime.

Pure magnesia does not form a sufficiently coherent mass, and, alumina being light and flocculent, allows the metal to sink through it.

The lime should be entirely free from silica, one-quarter per cent. being sufficient to spoil the surface.

The best method of preparing the lime is to ignite calcium carbonate which has been precipitated from calcium nitrate by ammonium carbonate.*

3. The hydrogen burned must contain no hydrocarbons.

At these high temperatures platinum combines readily with carbon, and any carbon in the flame would rapidly tarnish the surface of the metal.

4. The gases should be burnt in the ratio of four volumes of hydrogen to three of oxygen.

All the best results were obtained when using the gases in the above-mentioned proportion. The temperature of the flame is then but little above the melting point of platinum, and the metal does not superheat to any great extent. When the platinum is considerably superheated it slowly distils, the drops condensing on the brick forming the cover of the furnace; the metal then drips back into the crucible carrying with it some of the silica which the brick contains, and thus contaminating the surface which is under observation. An excess of oxygen in the flame is also favourable, inasmuch as it oxidises any impurity that the platinum may contain.

Finally it is important that the blow-pipe should be so constructed as to ensure a thorough mixture of the two gases.

The most favourable conditions being established by these preliminary experiments, the necessary apparatus had now to be designed. It may be thought that the instruments are unnecessarily complicated, but it must be borne in mind that a single experimenter had not only to make all the observations, but also to regulate the flow of the gases, the electromotive force on the terminals of the standard lamp, and the current of water passing through the diaphragms. Most of the apparatus had, therefore, to be made automatic in its action.

The instruments serving to regulate the supply of gas are shown in fig. 6. The gas supply is stored in large cylinders at a pressure of from 100 to 200 atmospheres. S is a device worked by an electric current from a key placed under the photometer head. When the key is pressed the chopper C falls, compressing the india-rubber tubes and cutting off the gas from the blow-pipe. (This device is shown in elevation at the bottom of fig. 6, on the left-hand side.) The hydrogen escapes through a valve to the burner B where it is ignited, the oxygen blows off through the water trap T. When the chopper C is up the gases, after passing through the meters provided with scales reading to one-hundredth of a cubic foot are burnt from the blow-pipe P.

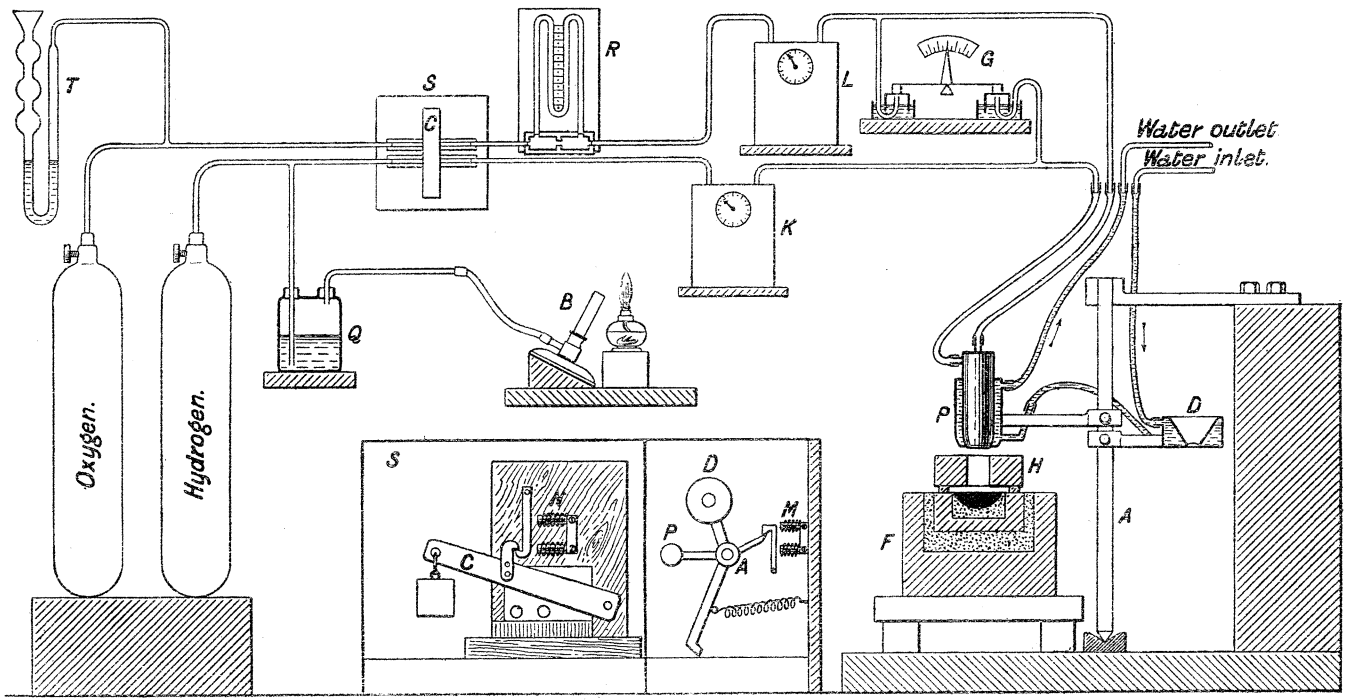
On one of the circuits the gas is forced through a diaphragm with an opening of about one-hundredth of the normal cross-section of the

* This method was suggested by Dr. A. Scott, to whose kind advice the solution of many of the chemical problems involved in the present work is due.

FIG. 6.—Apparatus used for fusing platinum with the oxy-hydrogen blow-pipe. T, oxygen blow-off valve; Q, hydrogen blow-off valve; S, automatic device for cutting off the gas from the blow-pipe (seen also in elevation in small inset figure at bottom); R, "rate" gauge; L and K, oxygen and hydrogen meters; G, "ratio" gauge; P, blow-pipe; D, diaphragm; H, cover of furnace; F, furnace; A, axis which supports the blow-pipe and diaphragm; M and N, electro-magnets.

The plan of the automatic device for replacing the blow-pipe by the diaphragm is shown in the right-hand small figure at bottom.

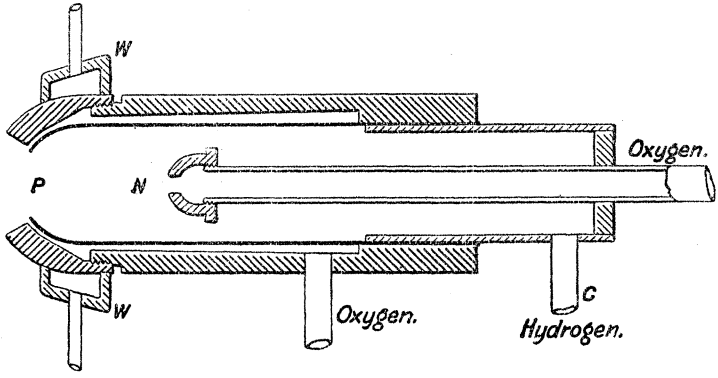
N.B.—This figure is a purely diagrammatic representation of the apparatus, and is not drawn to scale.



rubber tubes. The gauge R indicates the difference of pressure between the two sides of this diaphragm. By the aid of this gauge R the rate of flow of the gas can be kept constant at any desired value. The gauge G serves to regulate the ratio of the two gases. Two bells float in mercury, the interior of one being placed in communication with the oxygen inlet of the blow-pipe, the interior of the other with the hydrogen inlet. The apparatus is merely a balance, the two quantities weighed being the pressures of the two gases. The point of support is empirically adjusted so that the system is in equilibrium when the gases are flowing in the desired ratio, viz., four volumes of hydrogen to three of oxygen.

The instrument is very easy to construct, and its accuracy is amply sufficient for the purpose in view.

FIG. 7.—Blow-pipe. (Scale $\frac{3}{4}$ full size.)



The blow-pipe is of a somewhat peculiar shape and is shown in fig. 7. About half the oxygen passes through the central nozzle N, which is surrounded by a platinum nozzle P. The supply of hydrogen is led in at C, and flows down between these two tubes. The entire arrangement is surrounded by a gun-metal case, which is cooled by the water circulation W. Half the oxygen flows down between the gun-metal and platinum tubes, entirely surrounding the hydrogen where it issues from the platinum nozzle, thus insuring its perfect combustion.

The Furnace (F, fig. 6).—The outer shell consists of an ordinary Fletcher furnace, 23 cm. in external diameter. The interior is filled up to within 7 cm. of the top with sand, on which rests one of the ordinary magnesia bricks used for smelting platinum. Their chemical composition is—

Magnesia	92	per cent.
Lime	4·3	,,
Silica	2·4	,,
Iron and alumina	1·3	,,

These bricks are eminently suitable to resist high temperatures. Owing to the presence of silica they could not be used alone for the purpose we have in view, but they are very valuable as an outer crucible in which to place the pure lime on which the platinum rests. In a brick $11 \times 11 \times 7$ cm. a cylinder of 7 cm. in diameter and 3 cm. in depth is drilled out; the hollow is filled up with chemically pure lime in the form of powder, which is pressed tightly in. The platinum, roughly hammered into shape, is forced into the bed thus prepared until the lime is flush with the upper surface of the metal. Before the temperature has reached the melting point of platinum the lime has formed itself into a sufficiently coherent mass to support the weight of the metal. Another brick $11 \times 11 \times 4$ cm. forms the cover; it is held in a cast-iron frame by six $\frac{1}{4}$-inch screws equally spaced along two adjacent sides of the square. A hole 1·6 cm. in diameter is drilled through the centre of this cover. It is through this hole that the blow-pipe plays vertically on the surface of the metal. The lower surface of the cover should be not more than 1 cm. above the platinum. Both blow-pipe and diaphragm are attached to the same vertical axis A; the electromagnet M, which controls the motion of this axis, is placed in series with the magnet N, which cuts off the supply of gas to the blow-pipe. The instant the gas is stopped the axis swings round, bringing the 1 square centimetre diaphragm D above the hole in the cover of the furnace. A number of screens are provided so as to prevent any light from the furnace itself reaching the photometer. These screens have been removed in fig. 6 so as to give a better view of the furnace.

The light from the platinum is reflected on to the photometer by a mirror. The secondary standard is not placed in the axis of the photometer, but at right angles to it, its light being also reflected by a mirror. Each mirror is supported by a bar, which is held in a socket provided with a V-shaped check, so that when one of the mirrors is taken out of its supporting socket it can always be replaced in the same position; the fittings are made interchangeable. Thus by interchanging the two mirrors any error due to their coefficient of absorption can be eliminated.

A metronome ringing every ten seconds gives the intervals at which the photometric observations are to be made. To save time the readings are not taken, but the position of the index on the photometer bar is marked off. The distances are read at leisure later on.

The method by which the observations are obtained is as follows:— Let us suppose that the platinum is in position, the standard of reference adjusted, the metronome started, the "rate" and "ratio" gauges calibrated, and that we are ready to start the blow-pipe. We turn on the gas and increase the supply until the gauge shows that the hydro-

gen is burning at the rate of 0·8 cubic foot per minute, we then regulate the supply of gas so as to keep the ratio gauge in balance. At the end of fifteen minutes we press the key which stops the gas and swings the diaphragm into position. No photometric readings are taken at the end of this first fusion for two reasons: 1. The walls of the furnace have not yet had time to heat up, and the platinum, though fused on the surface, is probably still solid underneath. 2. Some particles of lime dust are pretty sure to be floating on the surface if the ingot of metal has only just been put into a newly made crucible. We therefore merely use this fusion to adjust the position of the furnace and cover, so that the centre of the platinum surface and the centre of the aperture in the cover should be on a vertical line passing through the centre of the diaphragm.

This done, we re-start the blow-pipe, and fifteen minutes later, as the metronome rings, we press the electric key, keeping an eye on the photometer. The photometer is kept in balance, and every ten seconds, as the metronome rings, the position of the photometer head is marked off. By the time some ten or fifteen readings have been recorded the platinum has cooled below its melting point. The distances are then read off at leisure, the blow-pipe is swung back into position, the chopper re-set, the mirrors are interchanged, and everything is ready for a fresh start. Fifteen minutes later another series of readings can be taken.

A Lummer and Brodhun photometer* and photometer bench were used during these experiments, the distance between the lights being 331·4 cm. The position of both the sources of light was fixed, the photometer head alone being movable. To ensure the maximum sensitiveness it is well to keep one eye exclusively for the photometric observations, covering it when the readings are not being taken with a black screen. In all the experiments incandescent lamps were used as standards of reference. When the necessary precautions are taken these form very reliable standards, remaining absolutely constant for many hours.† The pressure on the terminals of these lamps must be adjusted with the greatest care, as the light varies with the sixth power of the electromotive force. In the present case fifty-volt lamps were used, a specially constructed divided resistance being placed across the terminals of the lamp. By means of a potentiometer the electromotive force on 1/20th of this resistance was compared with the electromotive force of a Clark's cell. To avoid any rapid changes

* The photometer head and part of the photometer bench are shown in fig. 4. To avoid any stray light, the photometer was hung with black velvet curtains. These have been drawn aside in fig. 4. For a full description of this instrument see 'Zeitschrift für Instrumentenkunde,' p. 41, 1892, and 'J. für Gasbeleuchtung und Wasserversorgung,' vol. 37, p. 61, 1894.

† 'Zeitschrift für Instrumentenkunde,' vol. 10, p. 119, 1890.

of temperature the cell was placed in the inner chamber of a calorimeter. Under these circumstances the pressure on the terminals of the lamp could be kept constant during many hours to within one hundredth of a per cent.

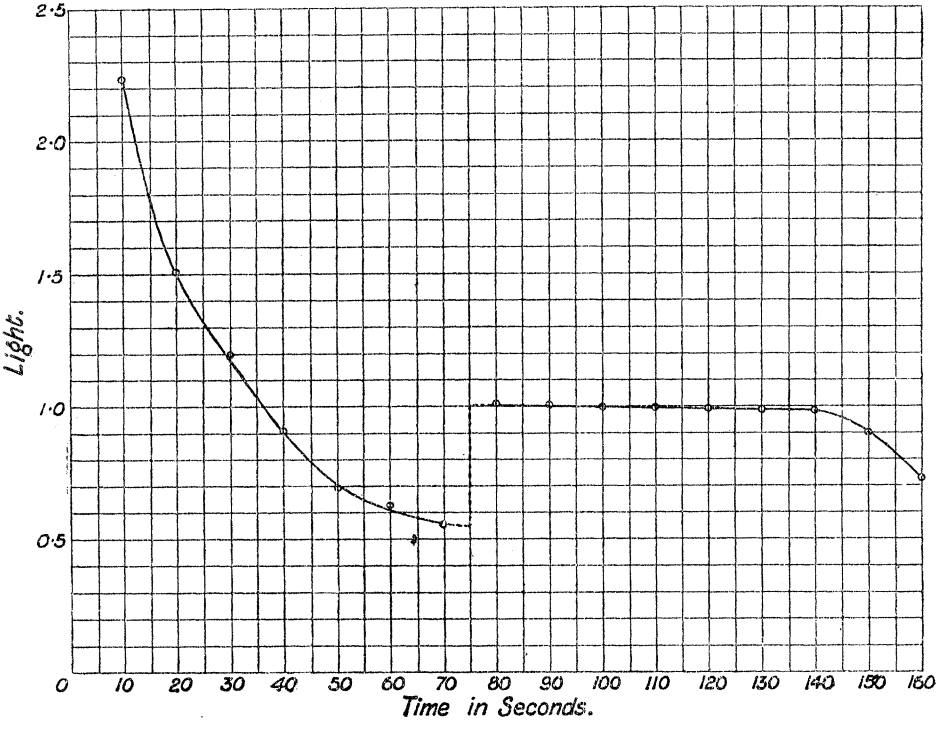
Table V. (See fig. 8.)—Normal Conditions.

Intensity of the Light from 1 sq. cm. of Platinum at the Temperature of Solidification as deduced from the observations given below is 1·002 (the error of this determination is therefore 0·002).

Time.	Photometer reading.	Light.
10	118·3	2·236
20	133·8	1·503
30	143·0	1·196
40	154·3	0·908
50	164·5	0·693
60	171·8	0·623
70	174·4	0·559
80	150·0	1·008
90	150·3	1·001
100	150·6	0·993
110	150·7	0·991
120	150·8	0·988
130	150·9	0·986
140	151·0	0·984
150	154·8	0·897
160	163·8	0·722

Having in the manner indicated above obtained a set of photometric readings at intervals of ten seconds from the time the blow-pipe was stopped, let us consider what is the best manner of reducing these observations. The typical shape of the curve obtained is shown in fig. 8 (see Table V); the abscissæ represent time, the ordinates light. The curve consists of three parts, the first falling rapidly represents the decrease of light sent out from the liquid metal as its temperature falls. There is a sudden break in the curve when the platinum begins to solidify, followed by a practically straight line. This second period (forty to fifty seconds in the conditions under which these experiments were made) marks the time during which the platinum ingot is freezing. For the sake of brevity we shall in future refer to this part of the curve as the "constant" period, though strictly speaking, owing to the imperfect conduction of the metal, the intensity of the light decreases slightly as the time increases. The third part of the curve represents the cooling of the surface after the entire mass is solid. The want of sharpness in the transition between the second and third parts

FIG. 8.—"Normal" conditions: total mass of platinum, 345 grammes; superficial area, 17 sq. cm.; diameter of aperture in the cover of the furnace, 1·6 cm.; intensity of the light at the temperature of solidification, 1·002 (the error of this determination is therefore 0·002).



is due to the fact that the heat lost at the surface is at first supplied by conduction from the lower layers still substantially at the temperature of solidification, and it is not until the corresponding temperature gradient is established throughout the entire mass that the normal rate of cooling is shown by the light given off from the surface.

Curves similar to the above, but referring to the case of molten silver, were shown by Violle in 1884.*

A second form of curve is possible (see figs. 9 and 11). This shape is obtained when the metal has been heated very slightly above its

* 'Annales de Chimie et de Physique,' sér. 6, vol. 3, p. 373, 1884; also Conférence Internationale pour la Détermination des Unités Électriques, séance de la Troisième Commission, 3 Avril, 1884. There is, however, one essential difference between the present results and those obtained by Violle. In the case both of silver and platinum Violle indicates the "flash" as occurring not before but after the constant period.

Table VI. (See fig. 9.)

Superficial area of Platinum Ingot 30 sq. cm.

Intensity of the Light from 1 sq. cm. of Platinum at the Temperature of Solidification = 1·012.

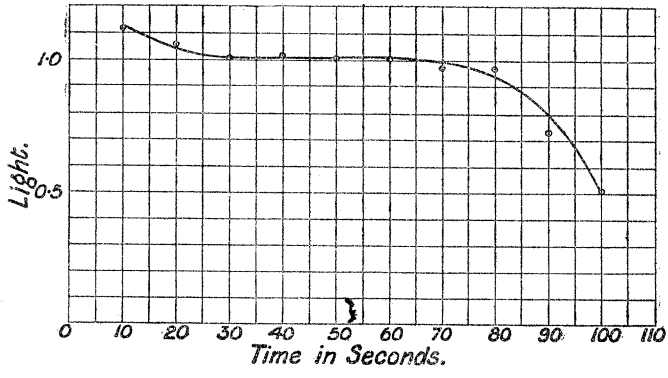
Time.[1]	Photometer reading.[2]	Light.[3]
10	145·7	1·119
20	148·2	1·054
30	150·1	1·005
40	149·8	1·013
50	150·1	1·005
60	150·3	1·001
70	151·5	0·972
80	151·7	0·967
90	163·3	0·730
100	178·8	0·502

[1] The time is counted from the instant at which the blow-pipe was stopped.

[2] The photometer reading is the distance in centimetres between the photometer head and the incandescent lamp which served as a standard of reference.

[3] The unit of light is the mean of a number of determinations made under the "normal" conditions.

Fig. 9.—Superficial area of platinum ingot, 30 sq. cm. (or 76 per cent. above the normal); intensity of the light at the temperature of solidification, 1·012 (or 0·012 above the normal).



melting point. In this case there is no flash up of the light, the three parts of the curve being continuous. The photometric readings, reduced as shown below, vary but little from those obtained when the curves are discontinuous, but for several reasons the results are likely to be less consistent than when the conditions are so regulated as to obtain the "flash" shown in fig. 8.

The definition of the standard quantity of light is that emitted in a normal direction by 1 square centimetre of surface of platinum at its temperature of solidification.

It has already been pointed out:

1. That it is practically impossible to obtain an instantaneous photometric observation.

2. That each part of the surface is, strictly speaking, only at the standard temperature for the small time-interval during which the solid film is actually forming.

3. That owing to the difficulties inherent to all photometric observations, each determination should rest on a number of separate readings.

The most obvious method would be to take the mean of the readings obtained during the "constant period," but in doing so we should certainly be wrong, as these readings form a decreasing series, the first one only being theoretically correct. The rate of decrease of the readings varies with the mass of metal used, and the circumstances under which it is allowed to cool; and were we to take the mean of the readings, the final determination would necessarily be dependent on these experimental conditions. The first reading, though theoretically the most correct, is practically the least reliable of the series. This reading immediately follows a sudden and considerable change in the illumination of the photometer, and the eye has not yet had time to become accustomed to the change. It is therefore out of the question to base our determinations on this first reading.

All things considered, it is best to establish the value of the intensity of the light emitted by the platinum at the instant of solidification by a graphical exterpolation.

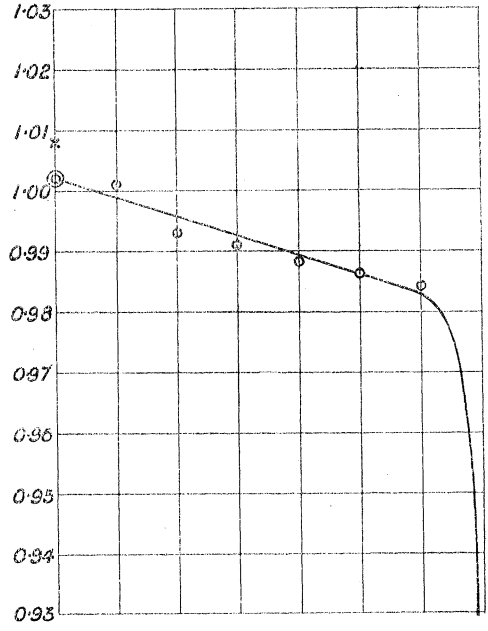
The shape of the curve during the period of solidification is, practically, a straight line. The various observations during this period differ but little in absolute value, and can easily be plotted to a very large scale. If we draw a straight line through these points the height of this line above the axis at the time at which the "flash" occurred will give us the quantity of light emitted at the temperature of solidification. The values of the observations themselves determine within ten seconds the time at which the "flash" occurred, and for a first approximation this is sufficient.

The above method of reducing the results is illustrated in fig. 10. After a set of observations has been taken, and while the platinum is still white-hot, the surface visible through the diaphragm should be inspected. Should any specks of lime dust or other impurity be apparent, the observations should be rejected.

It is advisable to make it a rule to discard any set of readings where:

1. The "constant period" extends over less than thirty seconds.

FIG. 10 (see Table V, fig. 8, and p. 495).—Illustrating the graphical method used in reducing the observations.



2. The mean rate of change of the intensity of the light during the so-called "constant period" exceeds 0·03 per cent. per second.

In the course of the present investigation, observations were taken for some three hundred curves, but for obvious reasons only a few of the most typical are recorded here.

It must be clearly understood that the present experiments were not undertaken with a view of obtaining any absolute determinations, but purely as a preliminary investigation. The objects in view were:

1. To ascertain the most favourable experimental conditions.

2. To determine the degree of accuracy to be obtained under these conditions.

The results are expressed in terms of the quantity of light emitted by 1 sq. cm. of platinum at its temperature of solidification, and under the following conditions:—

The total mass used was 345 grammes in the shape of a disc. The area of the upper surface of the disc was 17 sq. cm. The diameter of the hole in the cover of the furnace was 1·6 cm. The observations were taken after the blow-pipe had been alight for fifteen minutes, burning 0·8 cubic foot of hydrogen per minute, the two gases being mixed in the ratio of four volumes of hydrogen to three of oxygen. The above conditions will, for the purpose of this investigation, be taken as the "normal

conditions" (see Table V and fig. 8). It must, however, be borne in mind, that for the final experiments it would be advisable to increase the mass of metal to 1000 or 2000 grammes, and this would entail a change in the quantity of gas burnt.*

This said, let us proceed to determine to what extent the intensity of the light is dependent on the experimental conditions.

Change in the shape of the platinum ingot.—By changing the shape of the ingot we shall modify not only its rate of cooling, but also the maximum temperature it will reach under the "normal" supply of gas. If we flatten out the disc beyond a certain limit, only the central portion of the platinum will actually fuse. On the other hand, if we make the superficial area too small, forming the metal into a long cylinder, a limit will be reached when the fusion will cease to extend to the lower layers. In the present case 35 sq. cm. and 8 sq. cm. are

Table VII. (See fig. 11.)

Superficial area of Platinum Ingot 10 sq. cm.

Intensity of the Light from 1 sq. cm. of Platinum at the Temperature of Solidification = 1·004.

Time.[1]	Photometer reading.[2]	Light.[3]
10	141·8	1·232
20	144·8	1·144
30	148·8	1·038
40	148·3	1·050
50	149·6	1·018
60	150·3	1·001
70	150·0	1·008
80	150·1	1·005
90	150·2	1·003
100	150·2	1·003
110	151·5	0·972
120	152·8	0·942
130	154·0	0·915
140	154·2	0·910
150	164·8	0·704
160	173·3	0·573

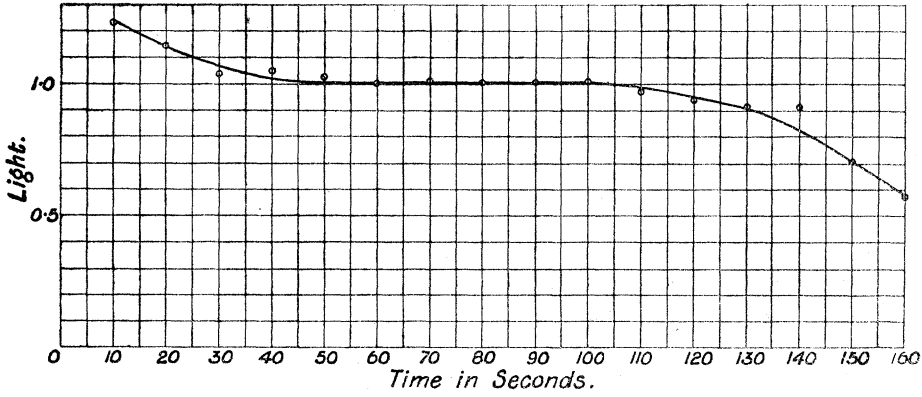
[1] The time is counted from the instant at which the blow-pipe was stopped.

[2] The photometer reading is the distance in centimetres between the photometer head and the incandescent lamp which served as a standard of reference.

[3] The unit of light is the mean of a number of determinations made under the "normal" conditions.

* It would also be advisable in future experiments to shape the platinum ingot into a half sphere, as this shape would be preferable with regard to the constancy of the observations during the time the metal is freezing.

FIG. 11.—Superficial area of the platinum ingot, 10 sq. cm. (or 41 per cent. below the normal); intensity of the light at the temperature of solidification, 1·004 (or 0·004 above the normal).



the limiting values. A number of determinations were made with a superficial area of 30 and 10 sq. cm. The details of two of the determinations are given in Tables VI and VII; the form of the curves is shown in figs. 9 and 11.

The maximum temperature reached by the metal was not sufficient to cause the sharp break in the curve of light, but notwithstanding this fact, the values obtained differ less than 1½ per cent. from the "normal" value. We are therefore justified in concluding that the intensity of the light is independent of the shape of the mass, so long as the entire mass is raised above its melting point.

Variation of the mass of metal used.—The effect of increasing the quantity of platinum from 345 to 510 grammes is shown in Table VIII and fig. 12. In this case the change produced in the light works out at 0·4 per cent. It is not possible to decrease the mass of metal much below 345 grammes, as the "constant period" becomes too short for reliable readings to be obtained. For 90 grammes, for instance (see fig. 13), the "constant period" has altogether disappeared, or, strictly speaking, it is only represented by a slight inflection in the curve. The experiments are, however, sufficient to show that though the mass of the ingot has a considerable effect on the degree of accuracy obtainable, it does not affect the quantity of light emitted at the temperature of solidification.

Variation in the shape of the enclosure.—From the laws of thermal radiation we are led to expect that the shape and temperature of the enclosure will have a considerable influence on the quantity of light emitted by such a body as platinum. Any change in size of the aperture in the cover of the furnace will greatly modify the rate of cooling of the metal, and from this cause also might affect the photo-

Table VIII. (See fig. 12.)

Mass of Platinum Ingot 510 grammes.

Intensity of the Light from 1 sq. cm. of Platinum at the Temperature of Solidification = 1·004.

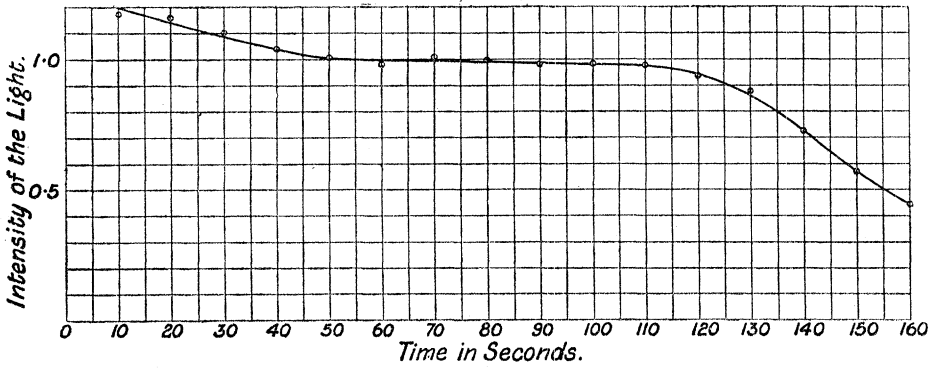
Time.[1]	Photometer reading.[2]	Light.[3]
10	143·8	1·173
20	144·6	1·150
30	146·5	1·098
40	148·8	1·038
50	150·1	1·005
60	150·8	0·988
70	150·3	1·001
80	150·4	0·998
90	150·9	0·986
100	151·0	0·984
110	151·2	0·979
120	152·8	0·942
130	155·8	0·875
140	163·8	0·722
150	173·8	0·567
160	183·8	0·444

[1] The time is counted from the instant at which the blow-pipe was stopped.

[2] The photometer reading is the distance in centimetres between the photometer head and the incandescent lamp which served as a standard of reference.

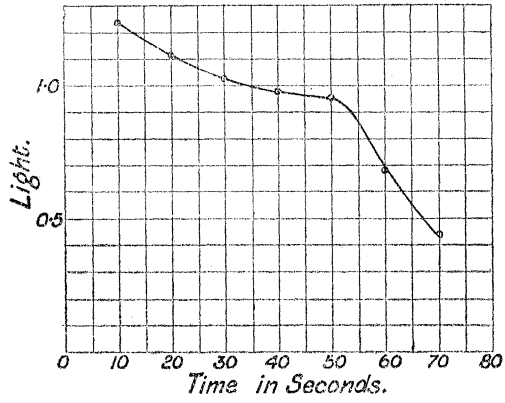
[3] The unit of light is the mean of a number of determinations made under the "normal" conditions.

FIG. 12.—Mass of the platinum ingot, 510 grammes (or 45 per cent. above the normal); intensity of the light at the temperature of solidification, 1·004 (or 0·004 above the normal).



metric observations. The "normal" conditions are chosen in order to make the rate of cooling as slow as possible, and any variation in the circumstances must necessarily cause the platinum to cool more rapidly.

FIG. 13.—Showing that when a small mass of platinum (90 grammes) is used, the light does not remain constant for any appreciable time.



One of the determinations made with the aperture in the cover 2·5 cm. in diameter, or nearly three times the area of the "normal" opening, is illustrated in fig. 14 (see Table IX). The quantity of light differs from the "normal" by less than 1 per cent. If the aperture in the cover is increased much beyond this limit, or if the cover is removed

Table IX. (See fig. 14.)

With the Diameter of the Opening in the Cover of the Furnace increased to 2·5 cm.

Intensity of the Light from 1 sq. cm. of the Platinum at the Temperature of Solidification = 1·005.

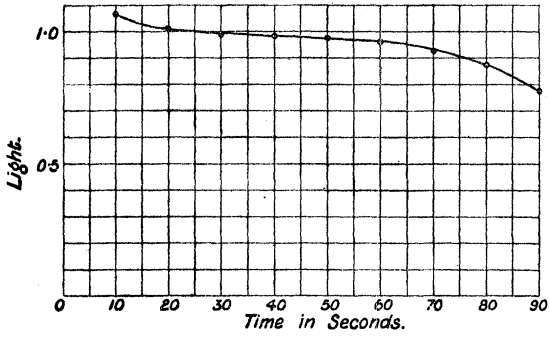
Time.[1]	Photometer reading.[2]	Light.[3]
10	147·8	1·064
20	150·0	1·008
30	150·7	0·991
40	150·9	0·986
50	151·3	0·976
60	152·0	0·960
70	153·6	0·924
80	155·8	0·875
90	160·8	0·776

[1] The time is counted from the instant at which the blow-pipe was stopped.

[2] The photometer reading is the distance in centimetres between the photometer head and the incandescent lamp which served as a standard of reference.

[3] The unit of light is the mean of a number of determinations made under the "normal" conditions.

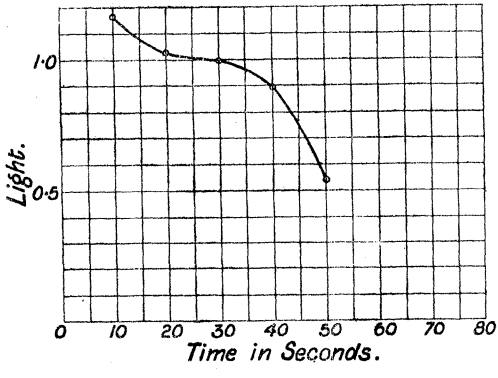
FIG. 14.—Area of the aperture in the cover, 4·9 sq. cm. (or 145 per cent. above the normal); intensity of the light at the temperature of solidification, 1·005 (or 0·005 above the normal).



altogether from the furnace, the constant part of the curve vanishes and determinations become impossible. This case is shown in fig. 15.

The recommendations made with regard to the rate at which the gases are to be burnt, and to the time during which the blow-pipe is to be alight, are only intended as an indication of the conditions under which the observations will be most easily obtained. A variation of 10 or even 20 per cent. in these factors would leave the final results practically unaffected, but a number of the observations would probably have to be discarded according to one or other of the three rules given on page 495.

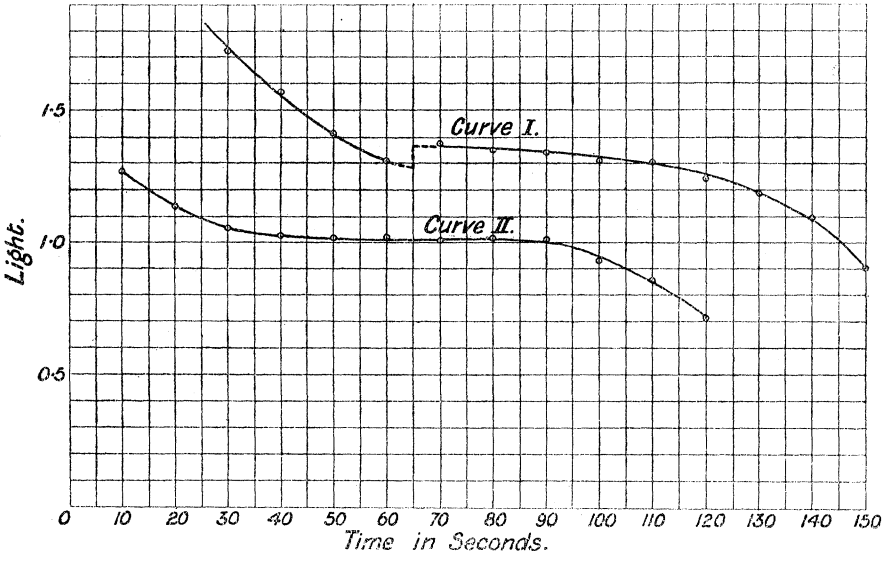
FIG. 15.—Showing the effect of removing the cover from the furnace.



The effect of contaminating the platinum with either silica or carbon is very marked. Carbon forms the best illustration, as there is no difficulty in subsequently getting rid of this impurity. On the 26th of March, after a certain number of normal determinations had been

made, it was decided to try the effect of using coal gas instead of hydrogen. After the blow-pipe had been supplied for twenty minutes with coal gas, the curve shown in fig. 16, curve I, was obtained; fifteen minutes later a similar set of readings were recorded. The

FIG. 16.—Curve I shows the effect of using coal gas to heat the platinum, the light is 36 per cent. above the normal. Curve II was taken an hour and a half later, the coal gas having been replaced by pure hydrogen. The error is already reduced to 2 per cent.



entire surface of the metal was covered with a white film. The intensity of the light was 36 per cent. above the normal. The coal gas was then stopped, and the hydrogen turned on, the surface gradually clearing as the carbon oxidised out. In an hour and a half the curve fig. 16, curve II, was obtained, the error having already been reduced to less than 2 per cent.

From the above results I believe I am justified in stating *that the probable variation in the light emitted by molten platinum under the standard conditions is not above 1 per cent.*

With more perfect apparatus, and with the experimental conditions altered in the direction that has been suggested, the accuracy of this standard would certainly be increased.

Physiological considerations fix a limit to the accuracy of photometric observations. It is not impossible that the accuracy of the platinum standard may attain to or even surpass this limit.

The present work has occupied nearly three years, and it was thought advisable before devoting more time to the subject to publish

such results as had already been obtained. It is hoped that those who are interested in photometric work will, by their advice and criticism, help to bring the research to a satisfactory close.

In concluding, may I be allowed to express my gratitude to the managers of the Royal Institution for placing the splendid resources of the Davy-Faraday Laboratory at my disposal, as well as for generously defraying the necessarily heavy expenses incurred by the present work.

My thanks are also due to Messrs. Johnson, Matthey & Co., who most kindly lent the platinum employed.

FIG. 1.

FIG. 2.—P, positive pole ; n_1, n_2, n_3, negative poles ; R_1, R_2, R_3, variable resistances ; B_1, B_2, B_3, batteries.

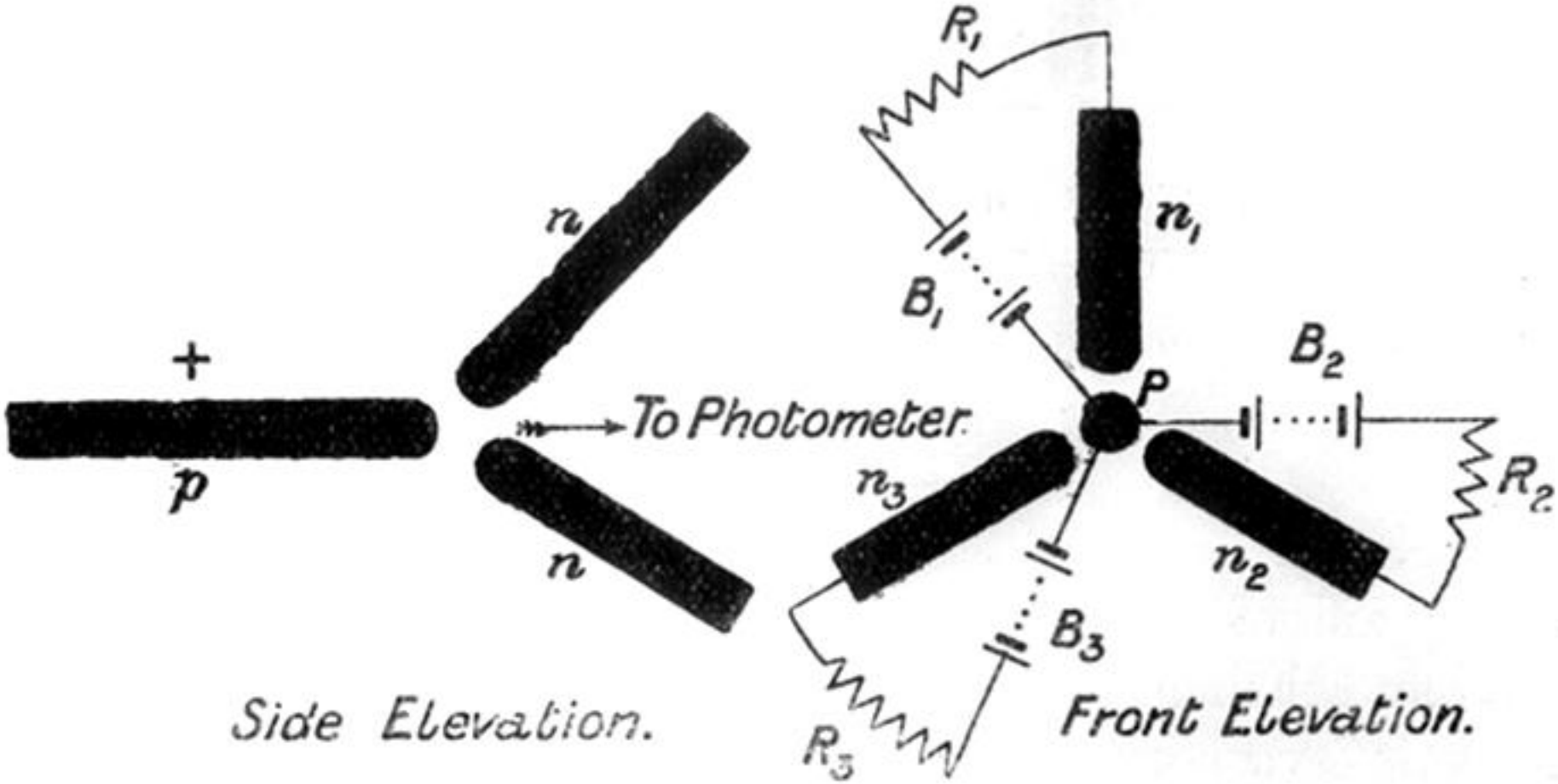
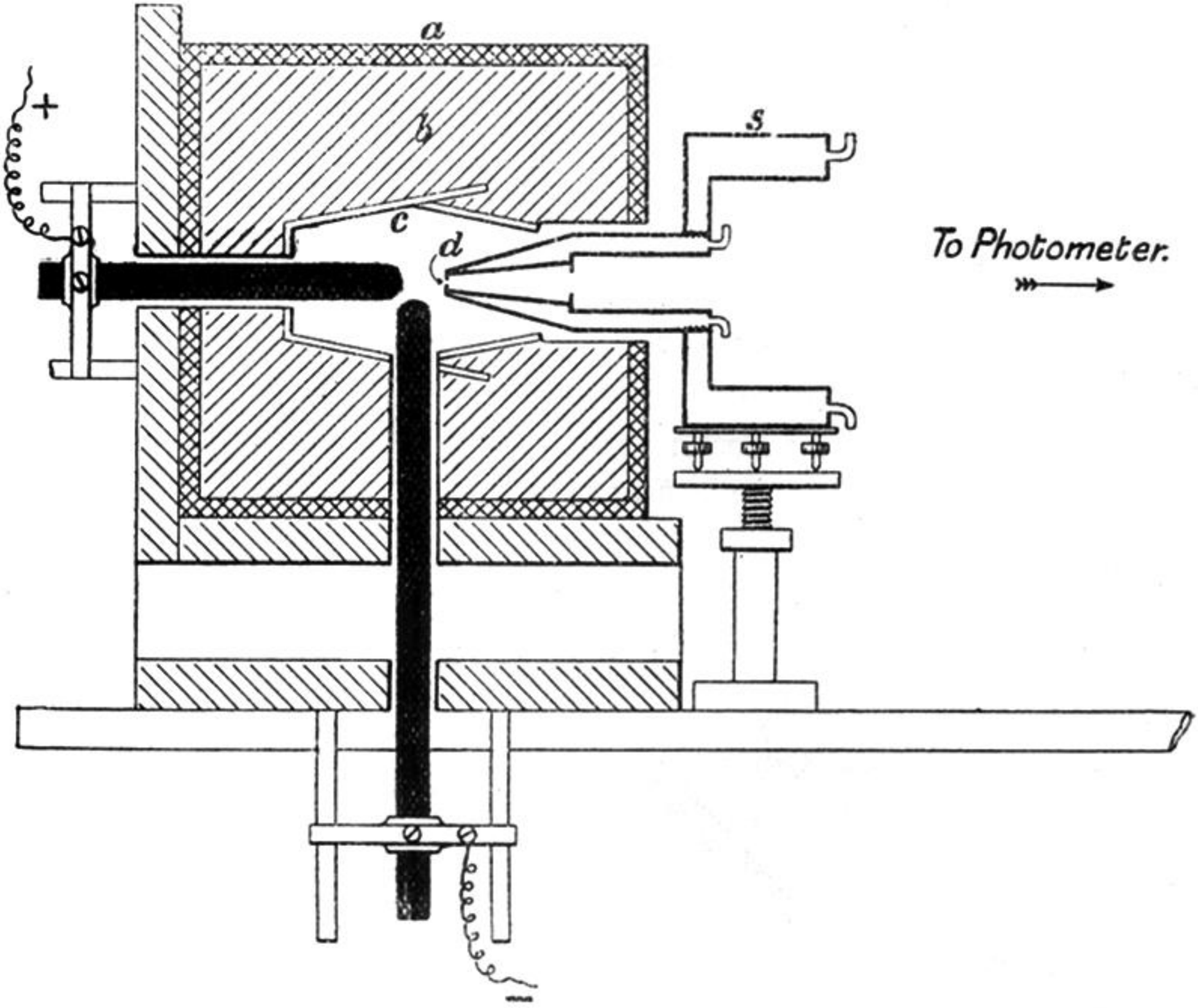


FIG. 3.—*a*, asbestos box; *b*, lining of refractory bricks; *c*, graphite crucible; *d*, diaphragm; *s*, screen.



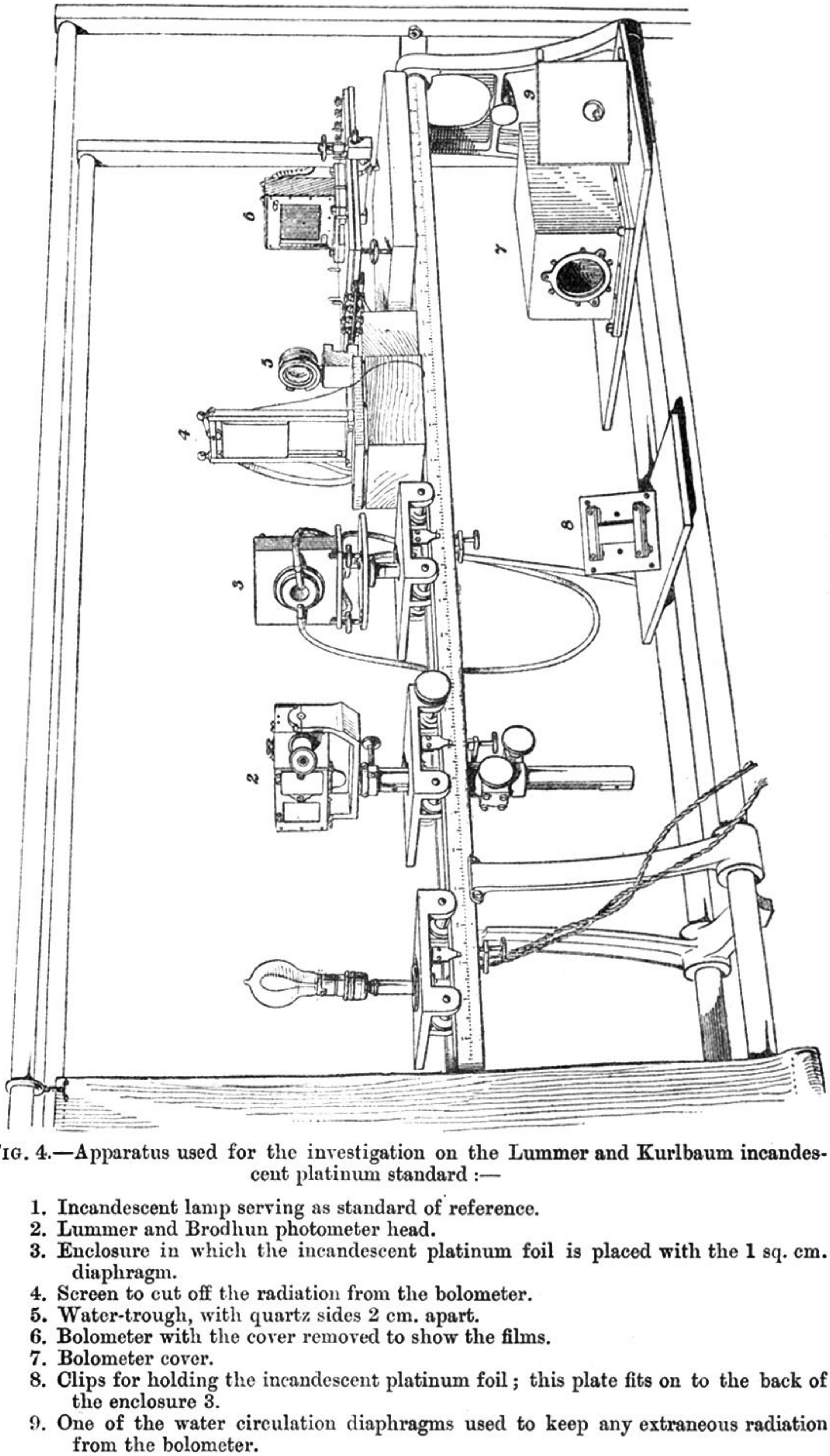


FIG. 4.—Apparatus used for the investigation on the Lummer and Kurlbaum incandescent platinum standard :—

1. Incandescent lamp serving as standard of reference.
2. Lummer and Brodhun photometer head.
3. Enclosure in which the incandescent platinum foil is placed with the 1 sq. cm. diaphragm.
4. Screen to cut off the radiation from the bolometer.
5. Water-trough, with quartz sides 2 cm. apart.
6. Bolometer with the cover removed to show the films.
7. Bolometer cover.
8. Clips for holding the incandescent platinum foil ; this plate fits on to the back of the enclosure 3.
9. One of the water circulation diaphragms used to keep any extraneous radiation from the bolometer.

FIG. 5.—Apparatus for the fusion of platinum bars by an electric current. A, platinum bar; C_1, C_2, copper clips in which the platinum is held; L, lime trough which supports the fused metal; R, mercury trough serving as a variable resistance; D, copper short-circuiting piece; S, mercury switch; T_1, T_2, massive copper leads to the battery terminals; I and O, water inlet and outlet.

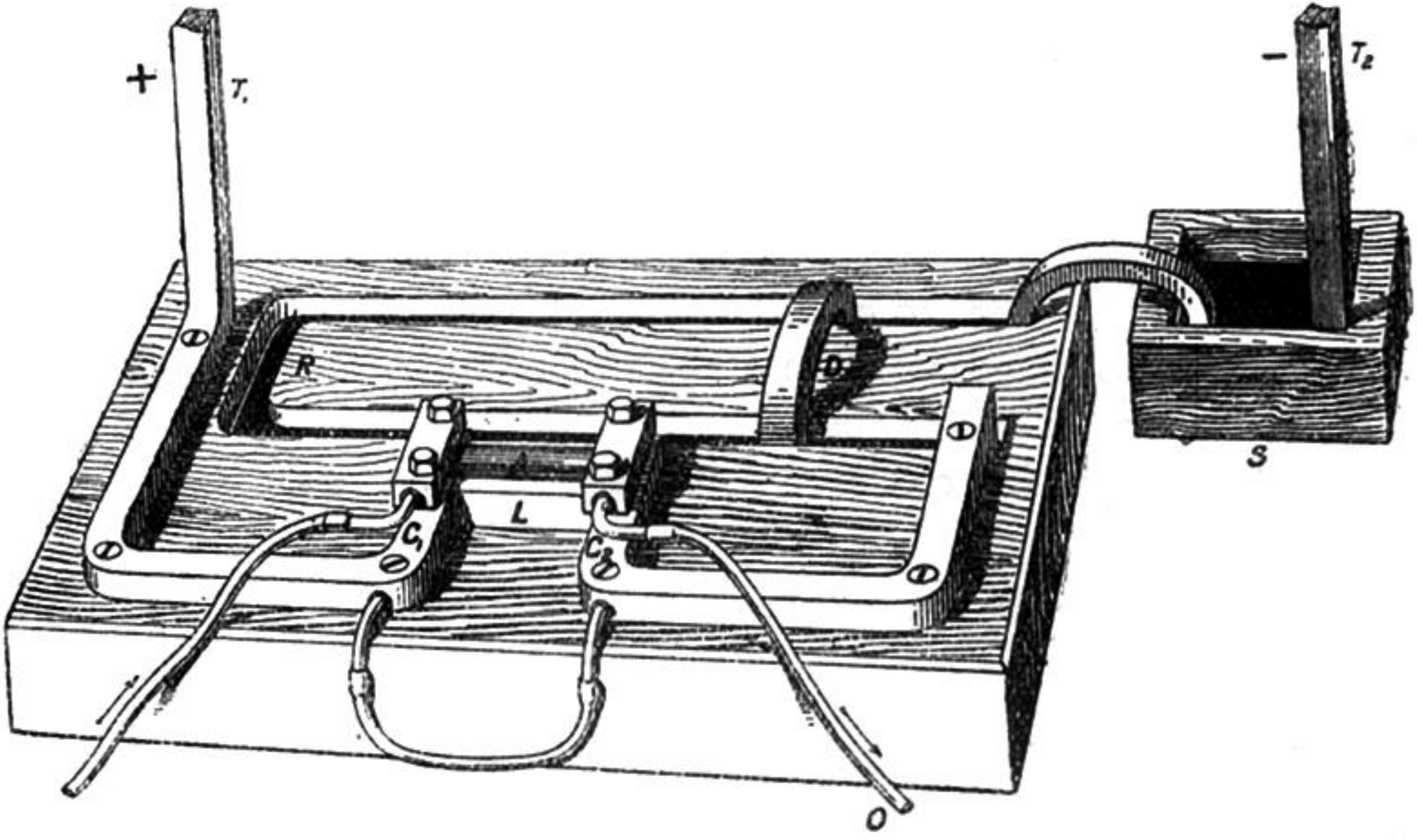


FIG. 6.—Apparatus used for fusing platinum with the oxy-hydrogen blow-pipe. T, oxygen blow-off valve; Q, hydrogen blow-off valve; S, automatic device for cutting off the gas from the blow-pipe (seen also in elevation in small inset figure at bottom); R, "rate" gauge; L and K, oxygen and hydrogen meters; G, "ratio" gauge; P, blow-pipe; D, diaphragm; H, cover of furnace; F, furnace; A, axis which supports the blow-pipe and diaphragm; M and N, electro-magnets.

The plan of the automatic device for replacing the blow-pipe by the diaphragm is shown in the right-hand small figure at bottom.

N.B.—This figure is a purely diagrammatic representation of the apparatus, and is not drawn to scale.

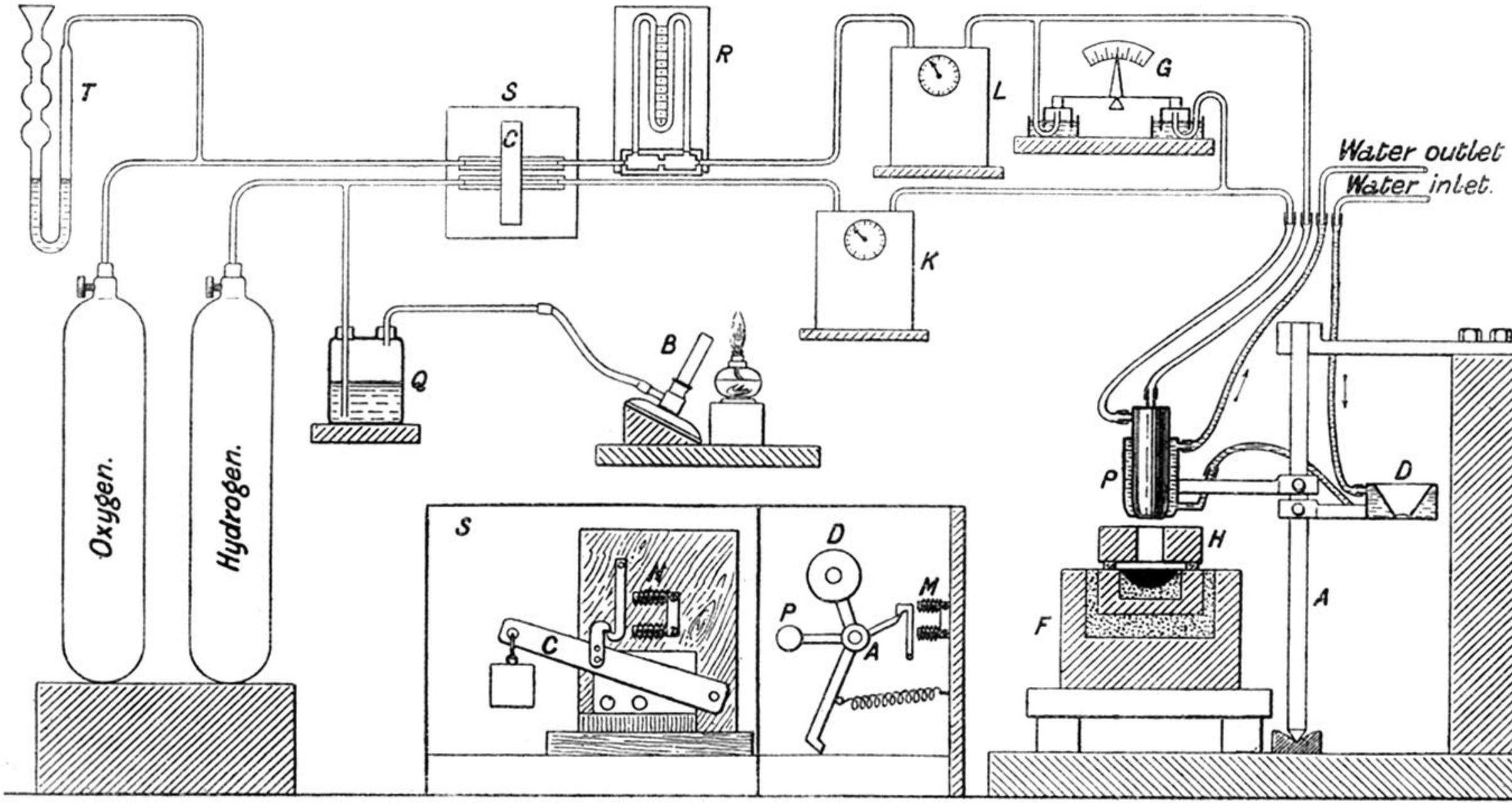


FIG. 7.—Blow-pipe. (Scale $\frac{3}{4}$ full size.)